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Seasonal patterns in the spatial overlap of southern Gulf of St. Lawrence cod and grey seals, with a discussion of sources of error and possible bias

Chevauchement spatial de la morue et du phoque gris du sud du golfe du Saint-Laurent selon les saisons, incluant une discussion sur les sources d'erreur et les biais possibles

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ABSTRACT

A Zonal Assessment Process on the potential impacts of grey seals on fish populations in eastern Canada was held during October 4-8, 2010. The terms of reference for that meeting included assessing the temporal and spatial overlap of grey seals and cod, as well as the possible sources of bias and uncertainty in estimates of the seasonal distribution of both species. This research document was prepared to address these questions as it relates to the southern Gulf of St. Lawrence (sGSL) cod population and to grey seals in the sGSL.

The spatial overlap of two size categories (<35 cm and ≥35 cm) of sGSL cod and grey seals was examined on a monthly timescale and a spatial scale of 1000s of km^2. The distribution of cod was inferred from seasonal bottom-trawl surveys and seasonal changes in the spatial distribution of cod-directed commercial fishing effort. The distribution of grey seals was inferred from the tracking of satellite-tagged individuals. There were strong herd, gender and stage-specific differences in grey seal movements. Juvenile and adult male grey seals from the Gulf herd overlapped most with southern Gulf cod, with a mean monthly average of 16% of the herd overlapping with cod. Overlap with seals from Sable Island was smaller (<1%).

Movement patterns of seals are inferred from a very small number of tagged seals, particularly given the need to account for gender and stage-specific differences in movements. Because of this low sample size, areas that are visited by only a small proportion of the herd have a high probability of being underrepresented in the inferred distributional areas, particularly when a fairly fine spatial resolution is used. To the extent that these are areas where cod occur, seal-cod overlap will be under or over-estimated. For periods when cod are aggregated (winter, spawning, migration) in particular, potential consumption of cod by seals may therefore also be underestimated. Unfortunately, the sample size of tagged seals is especially low during some of these periods. There are also likely biases in seal tagging with respect to haul-out site that may affect population-level inferences on grey seal distribution and movement.

The current spatial distribution of cod in months other than August and September can only be inferred from surveys that took place 15-20 years ago. The distribution is poorly known during some months, such as during cod migration. Furthermore, our characterization of monthly changes in distribution may not be entirely accurate given changes in the timing of spring and fall migrations.

RÉSUMÉ

Une évaluation zonale des répercussions potentielles de la présence des phoques gris sur les populations de poissons dans l'est du Canada a été effectuée du 4 au 8 octobre 2010. Le cadre de référence de cette réunion comprenait l'évaluation du chevauchement spatio-temporel du phoque gris et de la morue, ainsi que les sources possibles de biais et d'incertitude des estimés de la distribution saisonnière de ces deux espèces. Le présent document de recherche vise à répondre à ces questions concernant les populations de morue et de phoque gris du sud du golfe du Saint-Laurent (sGSL).

Le chevauchement spatial de la morue de deux catégories de taille (< 35 cm et ≥ 35 cm) et du phoque gris du sGSL a été examiné par mois, selon une échelle spatiale de 1 000 km^2. La distribution de morue a été déterminée d'après des relevés saisonniers de chalut de fond et les variations saisonnières dans la distribution spatiale de la pêche commerciale à la morue. La distribution du phoque gris a été déterminée d'après le suivi des animaux surveillés par satellite. De grandes différences ont été signalées quant aux troupeaux, au sexe et au stade de vie dans les déplacements du phoque gris. Les phoques gris mâles, juvéniles comme adultes, des troupeaux du sud du golfe du Saint-Laurent sont à l'origine du principal chevauchement avec la morue de cette zone, soit un chevauchement par 16 % de cette population de phoques en moyenne par mois. Le chevauchement avec les phoques de l'île de Sable était moindre (< 1 %).

Les déplacements de phoques sont déterminés d'après un très petit nombre de phoques marqués, d'autant plus qu'il faut tenir compte des différences relatives au sexe et au stade de vie dans les déplacements. En raison de la faible taille de cet échantillon, les zones visitées par une petite partie du troupeau risquent très probablement d'être sous-représentées dans les zones de distribution déterminées, surtout lorsqu'une résolution spatiale assez précise est utilisée. Le chevauchement entre le phoque gris et la morue peut être surestimé ou sous-estimé en fonction de la présence des populations de morue dans ces zones. Dans les périodes de concentration de morue (en hiver, période de frai, migration) en particulier, la consommation potentielle de morue par les phoques peut donc aussi être sous-estimée. Malheureusement, la taille de l'échantillon de phoques marqués est particulièrement faible pendant certaines de ces périodes. Le marquage des phoques donne aussi probablement lieu à des biais quant au site d'échouerie, ce qui peut influer sur les estimations de distribution et de déplacement des populations de phoque gris.

La distribution spatiale actuelle de morue dans les mois autres qu'août et septembre ne peut être déterminée que d'après des relevés effectués il y a 15 à 20 ans. On connaît peu la distribution de morue pendant certains mois, par exemple pendant la migration. De plus, notre estimé des variations mensuelles de distribution n'est peut-être pas tout à fait exact, étant donné les variations quant à la survenue des migrations du printemps et de l'automne.

OBJECTIVE

A Zonal Assessment Process on the potential impacts of grey seals (*Halichoerus grypus*) on fish populations in eastern Canada was held during October 4-8, 2010. The term of reference for the meeting included assessing the temporal and spatial overlap of grey seals and cod (*Gadus morhua*), as well as the possible sources of bias and uncertainty in estimates of the seasonal distribution of both species. This research document was prepared to address these questions as it relates to the southern Gulf of St. Lawrence (sGSL) cod population and to grey seals in the sGSL.

The spatial overlap of southern Gulf cod and grey seals was examined on a monthly timescale and a spatial scale of 1000s of km^2. The distribution of cod was inferred from seasonal bottom-trawl surveys (e.g., Darbyson and Benoît 2003) and seasonal changes in the spatial distribution of cod-directed commercial fishing effort. The distribution of grey seals was inferred from data from satellite-tagged individuals (Goulet et al. 2001; Breed et al. 2006; Harvey et al. 2008). Overlap was estimated for two cod size categories (<35 cm and ≥35 cm) and six grey seal categories: males, females and juveniles, from the Sable and Gulf herds. A Monte Carlo simulation was used to incorporate some of the uncertainty in the distribution of seals. There are important potential biases related in particular to the inferred distribution of grey seals which would affect perceived overlap. These biases could not be quantified, but are discussed in this working paper.

METHODS

COD

Information on the distribution of cod comes from two main sources: fishery independent bottom-trawl surveys and mobile-gear fishery logbooks.

A standardized bottom-trawl survey has been conducted each September since 1971 in the southern Gulf of St. Lawrence (Hurlbut and Clay 1990; Benoît and Swain 2003; Benoît 2006; Hurlbut et al. 2010). This survey is used to track interannual changes in the abundance and late-summer distribution of cod (Fig. 1) and numerous other species.

There have been additional surveys conducted in months other than September in the southern Gulf and Cabot Strait which provide a broad-scale picture of southern Gulf cod distribution. The protocols for these surveys were similar or identical to those used for the September survey, though in some cases different vessels or trawls were used (details are found in the individual papers cited below). A series of seasonal surveys were conducted in the south-eastern Gulf of St. Lawrence in 1986-1989 (Fig. 2; Clay 1991; Darbyson and Benoît 2003) and in the south-western Gulf in 1989-1992 (Fig.3; Darbyson and Benoît 2003). Surveys were also conducted on the southern Gulf cod overwintering grounds in the Cabot Strait each January from 1994-1997 (Fig. 4; Chouinard and Hurlbut, unpublished manuscript). Finally, a stratified random Sentinel Survey, which involves four commercial fishing vessels fishing the same type of trawl, has been conducted each August since 2003 (Fig. 5; Savoie and Surette 2010).

Commercial fishing occurred year-round prior to the 1993 moratorium on fishing of southern Gulf cod. Fishing would generally have targeted aggregations of cod. Information on cod-directed fishing effort from fish harvester logbooks therefore provides a picture of the seasonal changes in the distribution of cod aggregations (Fig. 6; Sinclair and Currie 1994; Comeau et al. 2002). Furthermore, standardized estimates of catch-per-unit-effort (CPUE) provide an

indication of the degree of spatial aggregation of commercial-sized cod: highest during the winter, lowest in August-October (Chouinard and Sinclair 1989).

Based on the above information, the seasonal distribution of southern Gulf cod can be summarized as follows (Figs. 7 and 8). Individuals overwinter in the deeper waters of Sydney Bight and along the southeastern slope of the Laurentian channel. Beginning in April, cod migrate into the sGSL following one of two routes: along the northwestern coast of Cape Breton Island, then westward north of PEI, or westward along the slope of the channel. Migration continues throughout May, with adult cod aggregating in the Shediac Valley and western portion of the Magdalen shallows in late May and June to spawn, while juvenile cod disperse throughout the southern Gulf. After spawning adult cod also distribute themselves broadly. Migration out of the Gulf appears to follow the same routes as the spring migration and begins in October, with peak migration now occurring in November (Comeau et al. 2002). By December, cod are now considered to be aggregated on their overwintering grounds.

For this working paper we considered the monthly spatial occupancy of the two size-classes of cod. Because cod distribution is related to bathymetry, survey strata (which are defined in large part by bathymetry) were used to summarize occupancy at a scale of 1000's km^2. This is likely the smallest scale feasible for examining cod-seal overlap, though we acknowledge that overlap at considerably finer scales is require for predation to occur. Given that there is little contemporary data on the seasonal distribution of cod, and that distribution was summarized merely as occupancy among strata, the impact of error in the inferred cod distribution on estimated overlap with seals was not considered.

GREY SEALS

Information on the movement of seals is based on sightings of marked seals and satellite tracking. The seasonal distribution of grey seals can be briefly described as follows. Grey seals breed on the drifting pack-ice or small islands in the sGSL (Gulf animals) or on Sable Island (Sable animals) during December-February. After breeding, animals disperse to feed. During moulting (May-June) animals spend more time ashore, dispersing once moulting is complete. Gulf animals may disperse to the Scotian Shelf, or other areas in the Gulf and estuary of the St. Lawrence, and Sable animals may disperse throughout the Scotian Shelf or move into the Gulf (Stobo et al. 1990; Lavigueur and Hammill 1993; Goulet et al. 2001; Austin et al. 2006; Breed et al. 2006; Harvey et al. 2008).

Here we focus on seal distribution as inferred from satellite tracking (details in Breed et al. 2006; Harvey et al. 2008). The distribution information is comprised of Bayesian State-Space model posterior estimates of underlying states (positions) at 8-hr intervals, inferred from the raw positions data (Jonsen et al. 2005). Previous analyses of these data have revealed strong herd, sex and stage-dependent differences in grey seal movements (Breed et al. 2006; Harvey et al. 2008). Consequently, the monthly spatial distribution for Gulf-tagged and for Sable-tagged seals was summarized by gender for adult seals, and for juveniles (Gulf) or young-of-the-year (Sable) separately. There were only six tagged seals from Sable Island that were juveniles in their second year of life or older and data from these seals were combined with the data for adults. Data for a particular seal in a given month were only retained if that seal was tracked for at least ten days. Some month-herd-'seal group' cells were represented by few or no seals, particularly in the spring (Table 1a). To increase the amount of data representing each cell, while respecting sex and stage-based differences, data from the months adjoining a month of interest were pooled (Table 1b). For example, the spatial distribution of grey seals in May was inferred from the tracking data collected in April to June.

Spatial overlap (o_{hgm}) in month m of seals in herd h and group g with cod was calculated as:

$$o_{hgm} = \sum_{i=1}^{N_{hgm}} \sum_{j=1}^{S_m} T_{ijm} \Big/ \sum_{i=1}^{N_{hgm}} T_{im}$$

where i is one of N_{hgm} greys seals that had a transmitting satellite-tag in herd h, group g and month m, S_m is the total number of strata occupied by cod during month m (see Figs. 7 and 8), and T_{ijm} is the total number state-space model posterior mean states for seal i that fell in stratum j during month m. (T_{im} is the total number of states for seal i in month m, irrespective of stratum). Variability in overlap was examined by bootstrapping the seal positions data, treating individual seals within the herd and seal groups as sampling units, and recalculating o_{hgm} each time. One thousand bootstrap iterations were deemed sufficient to characterize the variability in overlap caused by variation in grey seal distribution based on the satellite-derived data.

RESULTS AND DISCUSSION

Cod in both size groups overlap the most in all months with grey seals tagged in the Gulf (Table 2). Overlap is greatest with juvenile and male Gulf grey seals. The percentage of these seals overlapping with cod <35 cm varies from approximately 5-8% in November and 11-13% during the winter, to over 20% during the summer. Based on the defined distribution of cod, overlap with cod ≥35 cm is the same as cod <35 cm during the winter, but less during the summer. Overlap between cod and female Gulf seals typically varies between 2-12%. During cod spawning, overlap varies from 8% with female Gulf seals to 15.5% with Gulf juveniles, though in all cases these estimates are based on very few transmitting tagged seals (Table 1).

During the winter, approximately 0.1% of males and 0.8% of females from Sable Island overlap with southern Gulf cod (Table 2). When the area in the northern portion of NAFO 4Vs (i.e., pink area in Figs. 7 and 8) is included as a cod overwintering area, the overlap with the females increases considerably in some months. During the summer, approximately 2% of young-of-the-year, 2-4% of male and 0.2-1% of female grey seals from Sable Island overlap with cod in both size classes

POSSIBLE SOURCES OF BIAS AND ERROR

A principal assumption of the analyses above is that tagged seals form a representative sample of seals in both the Gulf and Sable Island herds (i.e., the movement of these seals reflects movements in the population). Unrepresentative tagging of seals, particularly in the Gulf population, is an important source of potential bias for inferences drawn on the distribution and movement of seals. Aerial surveys conducted in the mid-1980s (Clay and Nielsen 1985) and mid 1990s (Robillard et al. 2005) provide an indication of the spatial distribution of hauled-out grey seals in the Gulf of St. Lawrence. Both surveys found that a majority of grey seals in the Gulf were hauled out on Anticosti Island during the summer (the season during which most tagging took place), and that a considerably smaller proportion was found in the Northumberland Strait (Table 3). This perceived distribution is corroborated by information on the relative distribution of bounty kill locations for grey seals during the early 1980s (Lavigueur and Hammill 1993). In contrast, the majority of seals tagged in the Gulf was in Kouchibouguac, western Northumberland Strait, and only 17 % of tagged seals were from Anticosti (Table 3). To

the extent that movement patterns are haul-out site-specific, the movements of tagged seals will not be representative of movements within the Gulf herd. The satellite-tagging data suggest that this might be the case, as seals tagged at Anticosti Island tend to remain around the Island for some time, and then tend to move around Cape Breton Island and onto the Scotian shelf (Fig. 9). In contrast, seals tagged at Kouchibouguac spend a considerable amount of time in the southern-most portion of the Gulf. Also of note is an absence of seals tagged at the Magdalen Islands and in parts of the southeastern Gulf (Table 3).

Though it is conceivably considerably easier to obtain a representative sample of tagged seals from Sable Island, there is nonetheless the potential for bias. Most satellite tagging occurs after the annual moult (to minimize unnecessary tag loss). At that point, seals that normally breed on Sable Island may have dispersed to other areas, including the Gulf of St. Lawrence. Seals tagged on Sable Island will therefore not necessarily be representative of those that breed there.

Movement patterns of seals are inferred from a very small number of tagged seals, particularly given the need to account for gender and stage-specific differences in grey seal movements. Because of this low sample size, areas that are visited by only a small proportion of the herd have a high probability of being underrepresented in the inferred distributional areas. To the extent that these are areas where cod occur, seal-cod overlap will be underestimated. For periods when cod are aggregated (winter, spawning, migration) in particular, potential consumption of cod by seals may therefore also be underestimated.

The current spatial distribution of cod in months other than August and September can only be inferred from surveys that took place 15-20 years ago. For many of these months, cod are highly aggregated in known areas and it is likely that at the stratum scale, the distribution presented here is accurate. However for the months covering the migration, the distribution is considerably less well known. Furthermore, our characterization of monthly changes in distribution may not be entirely accurate given changes in the timing of spring and fall migrations (Sinclair and Currie 1994; Comeau et al. 2002), and possibly of spawning. Additionally, we have made no attempt to account for differences in cod density among occupied strata. Accounting for density would certainly affect the estimated overlap with seals, though it is not clear what the magnitude or direction of the effect would be.

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Table 1. a) Number of seals tracked for ten or more days in a given month by tagging area, gender and stage. b) Number of seals tracked for ten or more days in a three-month period centered on the indicated month, by area, gender and stage (e.g., summary for January is based on satellite tracking in December, January and February).

		Gulf			Sable		
	Month	Juveniles	Males	Females	YOY	Males	Females
a)							
	1	16	11	11	13	21	20
	2	13	14	9	12	19	20
	3	11	12	9	9	12	11
	4	1	10	3	7	6	5
	5	0	4	1	4	2	1
	6	6	8	4	24	16	17
	7	9	11	6	23	16	17
	8	12	9	5	22	16	17
	9	19	9	11	19	23	24
	10	20	12	12	18	43	46
	11	18	11	11	17	46	51
	12	18	11	11	14	40	48
b)							
	1	18	14	11	14	45	57
	2	16	14	11	13	27	28
	3	13	14	9	12	19	20
	4	11	12	9	9	12	11
	5	7	17	6	24	21	21
	6	9	15	6	24	17	17
	7	12	13	7	24	16	17
	8	19	13	13	23	23	24
	9	21	13	12	22	43	48
	10	21	12	12	19	47	54
	11	20	12	12	18	47	52
	12	18	11	11	17	47	53

Table 2. Average monthly proportion overlap (s.d.) of grey seals and cod a) <35 cm or b) ≥35 cm. Overlap is presented for each seal herd (Gulf, Sable Island), gender (male, female; adults only) and stage (juveniles in the Gulf, YOY from Sable Island, adults), and for overlap excluding and including the area in the northern portion of NAFO 4Vs that is potentially occupied by cod during the winter (i.e., pink area in Figs. 7 and 8).

	Gulf			Sable Island		
Month	Juveniles	Males	Females	YOY	Males	Females
a) Cod <35 cm						
1	0.140 (0.046)	0.131 (0.058)	0.049 (0.030)	0	0.001 (0.001)	0.01 (0.006)
2	0.130 (0.038)	0.116 (0.048)	0.029 (0.013)	0	0.002 (0.002)	0.019 (0.012)
3	0.130 (0.041)	0.111 (0.053)	0.023 (0.014)	0	0.002 (0.002)	0.009 (0.007)
4	0.137 (0.060)	0.084 (0.049)	0.041 (0.037)	0	0	0
5	0.206 (0.066)	0.132 (0.039)	0.075 (0.050)	<0.001	0	0.009 (0.005)
6	0.264 (0.040)	0.180 (0.037)	0.113 (0.071)	0.005 (0.005)	0.012 (0.01)	0.013 (0.006)
7	0.237 (0.038)	0.222 (0.040)	0.109 (0.065)	0.012 (0.012)	0.028 (0.027)	0.01 (0.005)
8	0.158 (0.038)	0.211 (0.043)	0.066 (0.039)	0.022 (0.022)	0.036 (0.035)	0.003 (0.003)
9	0.172 (0.035)	0.262 (0.044)	0.094 (0.032)	0.026 (0.026)	0.04 (0.032)	0.007 (0.006)
10	0.126 (0.028)	0.328 (0.062)	0.117 (0.041)	0.008 (0.008)	0.022 (0.015)	0.016 (0.012)
11	0.045 (0.018)	0.082 (0.046)	0.004 (0.002)	0.004 (0.004)	0.004 (0.003)	0.001 (0.001)
12	0.104 (0.041)	0.112 (0.068)	0.034 (0.029)	0	0.001 (0.001)	0.005 (0.004)
Including northern 4Vs						
1	0.173 (0.054)	0.154 (0.059)	0.049 (0.032)	0	0.001 (0.001)	0.033 (0.028)
2	0.178 (0.051)	0.134 (0.051)	0.030 (0.014)	0	0.004 (0.003)	0.042 (0.031)
3	0.155 (0.047)	0.125 (0.053)	0.025 (0.016)	0	0.002 (0.002)	0.009 (0.007)
4	0.137 (0.059)	0.085 (0.050)	0.040 (0.037)	0	0	0
12	0.099 (0.040)	0.114 (0.069)	0.034 (0.029)	0	0.001 (0.001)	0.005 (0.004)
b) Cod ≥35 cm						
1	0.139 (0.047)	0.131 (0.057)	0.049 (0.031)	0	0.001 (0.001)	0.009 (0.006)
2	0.129 (0.039)	0.115 (0.048)	0.028 (0.013)	0	0.002 (0.002)	0.018 (0.013)
3	0.128 (0.039)	0.106 (0.052)	0.023 (0.015)	0	0.002 (0.002)	0.008 (0.007)
4	0.137 (0.059)	0.083 (0.050)	0.039 (0.037)	0	0	0
5	0.212 (0.067)	0.135 (0.042)	0.076 (0.051)	<0.0001	0	0.009 (0.004)
6	0.155 (0.044)	0.116 (0.029)	0.080 (0.052)	0	0.001 (0.001)	<0.001
7	0.072 (0.024)	0.067 (0.027)	0.026 (0.011)	0.012 (0.012)	0.027 (0.025)	0.007 (0.003)
8	0.036 (0.011)	0.066 (0.029)	0.014 (0.006)	0.023 (0.022)	0.036 (0.033)	0.002 (0.002)
9	0.070 (0.019)	0.125 (0.047)	0.023 (0.011)	0.027 (0.026)	0.041 (0.032)	0.006 (0.006)
10	0.126 (0.028)	0.329 (0.062)	0.117 (0.042)	0.008 (0.008)	0.021 (0.015)	0.016 (0.011)
11	0.045 (0.018)	0.082 (0.046)	0.004 (0.002)	0.004 (0.004)	0.004 (0.003)	0.001 (0.001)
12	0.100 (0.039)	0.107 (0.068)	0.035 (0.003)	0	0.001 (0.001)	0.005 (0.004)
Including northern 4Vs						
1	0.171 (0.054)	0.151 (0.059)	0.050 (0.031)	0	0.001 (0.001)	0.034 (0.028)
2	0.18 (0.052)	0.136 (0.051)	0.030 (0.014)	0	0.004 (0.003)	0.042 (0.03)
3	0.153 (0.049)	0.124 (0.053)	0.025 (0.015)	0	0.002 (0.002)	0.008 (0.007)
4	0.137 (0.058)	0.088 (0.053)	0.041 (0.036)	0	0	0
12	0.101 (0.041)	0.110 (0.070)	0.034 (0.029)	0	0.001 (0.001)	0.005 (0.004)

Table 3. Seasonal and spatial distribution of hauled-out grey seals (percentage, with number observed in parentheses) based on the sightings surveys of i) Clay and Nielsen (1985) and ii) Robillard et al. (2005). iii) The locations of satellite tagging of seals in the Gulf (percentage, with number observed in parentheses).

Date	Area:					Northumberland Strait			
	Nfld (west coast)	Quebec Northshore	Anticosti Island	Gaspé peninsula	Magdalen Islands	Western portion	Eastern portion	Total	Cape Breton
i. Sightings (Clay and Nielsen)									
May 1983	0.3 (7)	0 (0)	99.9 (2232)	0.7 (16)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Aug. 1983	19.7 (195)	0 (0)	71.3 (706)	4.6 (45)	0 (0)	1.2 (12)	3.0 (30)	4.2 (42)	0.2 (2)
Nov. 1983	0.2 (2)	0 (0)	55.6 (714)	11.8 (151)	23.4 (300)	7.9 (101)	0.9 (11)	8.7 (112)	0.39 (5)
Jan. 1984	0	-	0.4 (2)	0.9 (4)	44.6 (210)	0.6 (3)	53.5 (252)	54.1 (255)	0 (0)
ii. Sightings (Robillard et al.)									
June 1996	------	4.5 (111)	86.2 (2110)	0.9 (22)	6.2 (151)	2.3 (55)	----------Not surveyed----------		
iii. Satellite tagging locations									
Mainly summer (1993-2008)	0 (0)	0 (0)	17.2 (10)	5.2 (3)	0 (0)	67.2 (39)	10.3 (6)	77.6 (45)	0 (0)

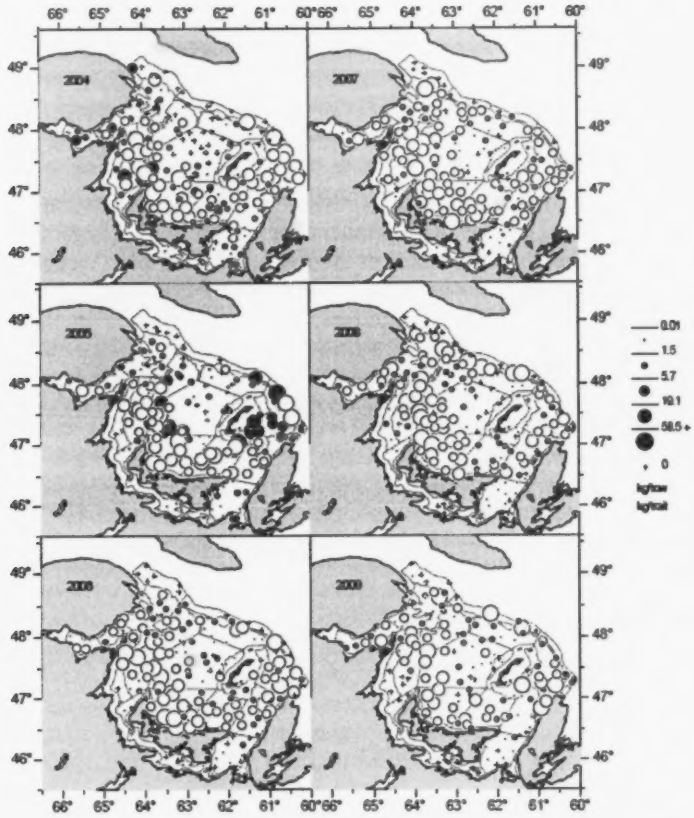

Figure 1. Cod catches (kg/tow) in the southern Gulf of St. Lawrence September bottom-trawl surveys from 2004 to 2009 (Black circles= catches by CCGS Alfred Needler; White= catches by CCGS Teleost). Figure taken from Hurlbut et al. (2010).

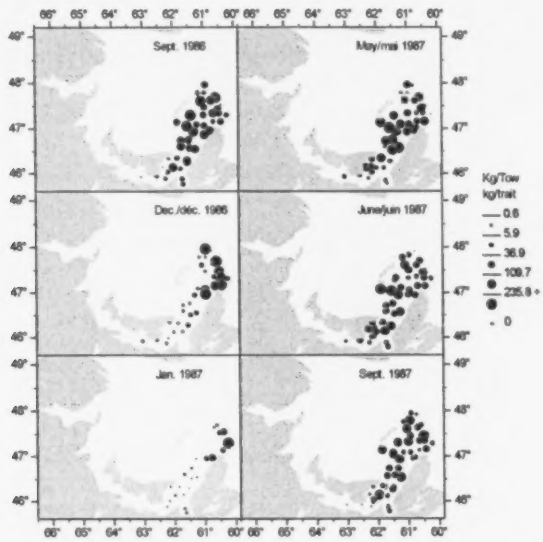

Figure 2. Cod catches (kg/tow) during the seasonal surveys of the south-eastern Gulf of St. Lawrence. Figure taken from Darbyson and Benoît (2003).

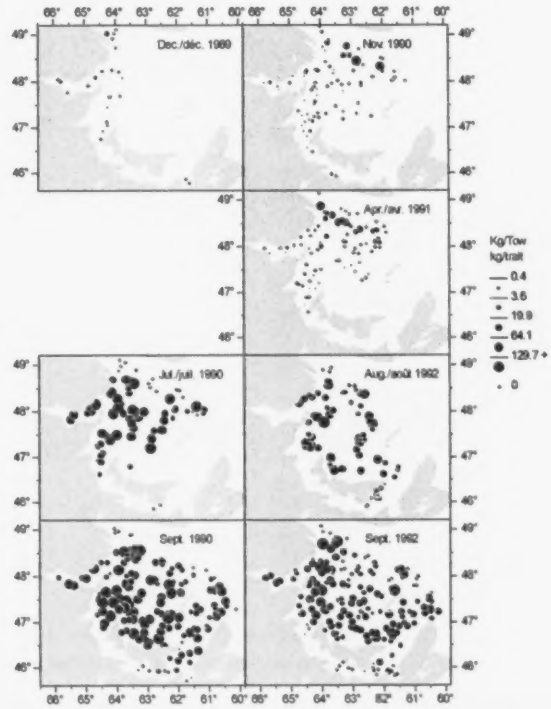

Figure 3. Cod catches (kg/tow) during the seasonal surveys of the south-western Gulf of St. Lawrence. Figure taken from Darbyson and Benoît (2003).

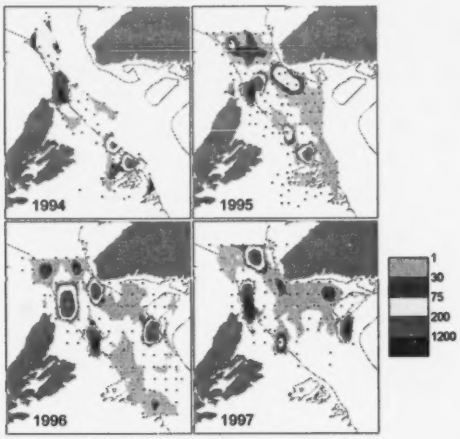

Figure 4. Cod catches (kg/tow) during the January surveys conducted in Cabot Strait, 1994 –1997.

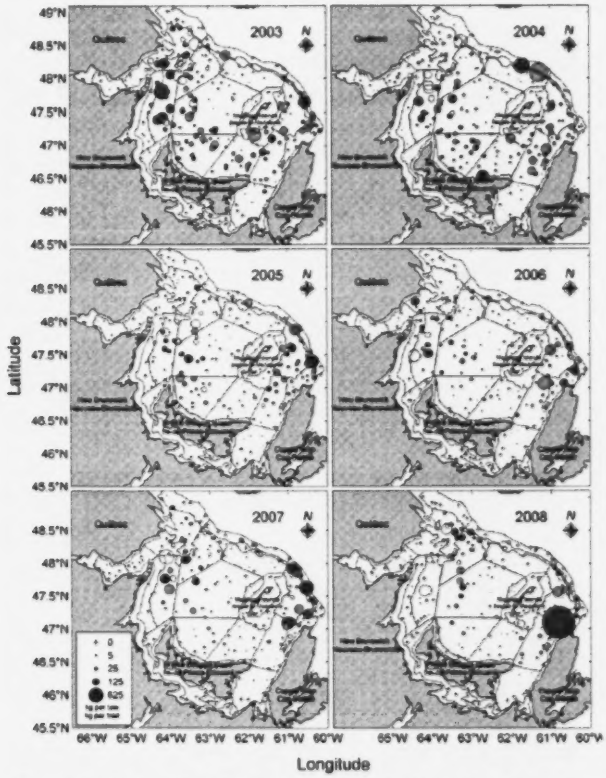

Figure 5. Cod catches (kg/tow) during the August sentinel bottom-trawl surveys, with different coloured circles representing different vessels. Figure taken from Savoie and Surette (2010).

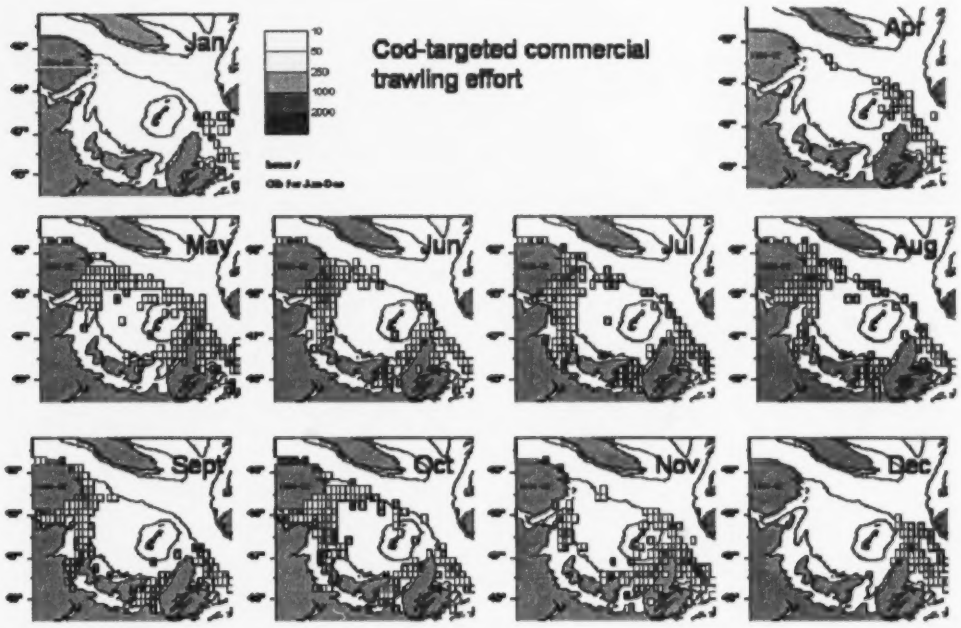

Figure 6. Monthly spatial distribution of cod-directed trawl fishing effort in 1992-1993. Note that no effort was reported in February or March.

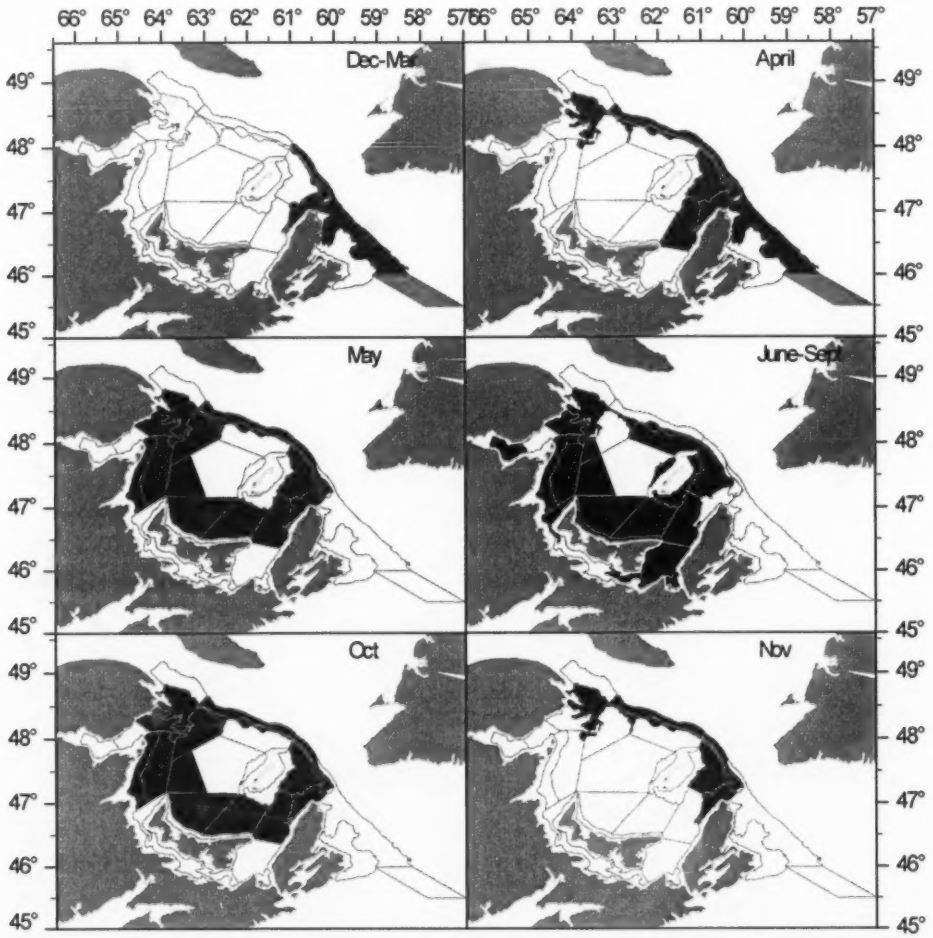

Figure 7. Inferred spatial distribution (i.e., stratum occupancy, coloured areas) of southern Gulf cod <35cm. Areas coloured in red indicate strata occupied by aggregated cod, strata in blue are occupied by dispersed cod and areas in purple are those through which aggregated cod move during their annual spring or fall migrations. The area coloured in pink (northern portion of NAFO 4Vs) is an area believed to be occupied by southern Gulf cod during winter in at least some years, based on fishery logbook information (Sinclair and Currie 1994).

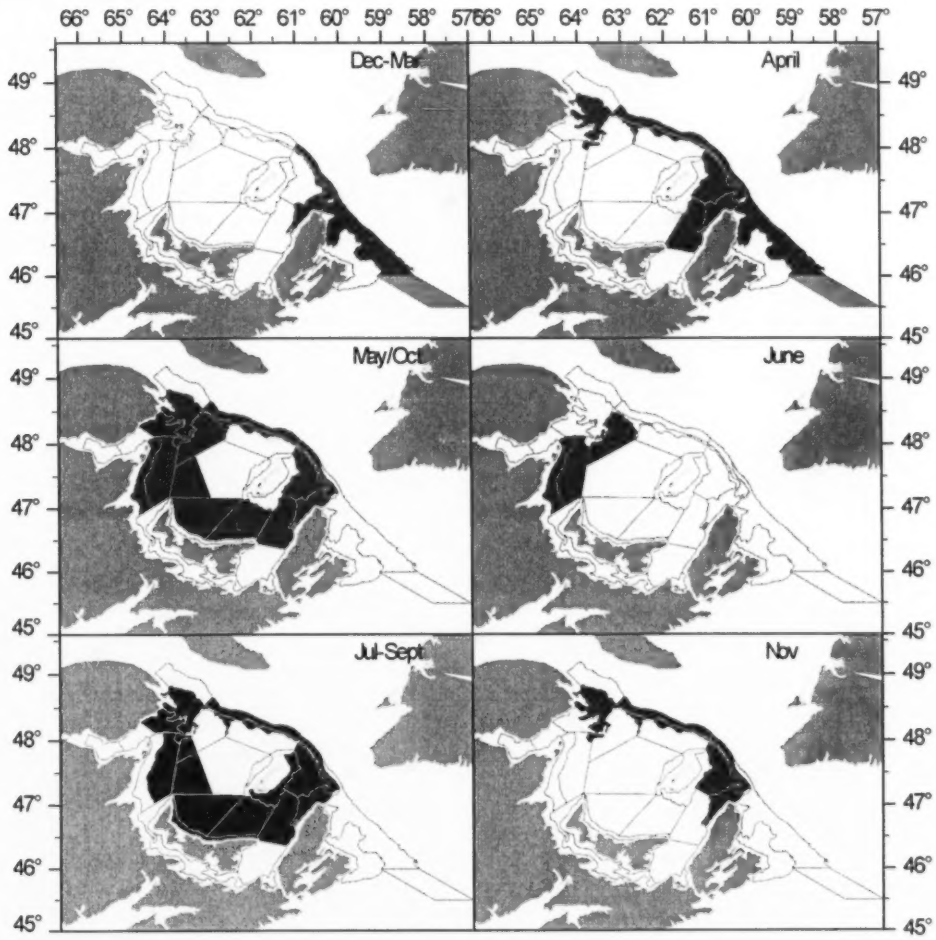

Figure 8. Inferred spatial distribution (i.e., stratum occupancy, coloured areas) of southern Gulf cod ≥35 cm. See the caption for Fig. 7 for an explanation of the colours used.

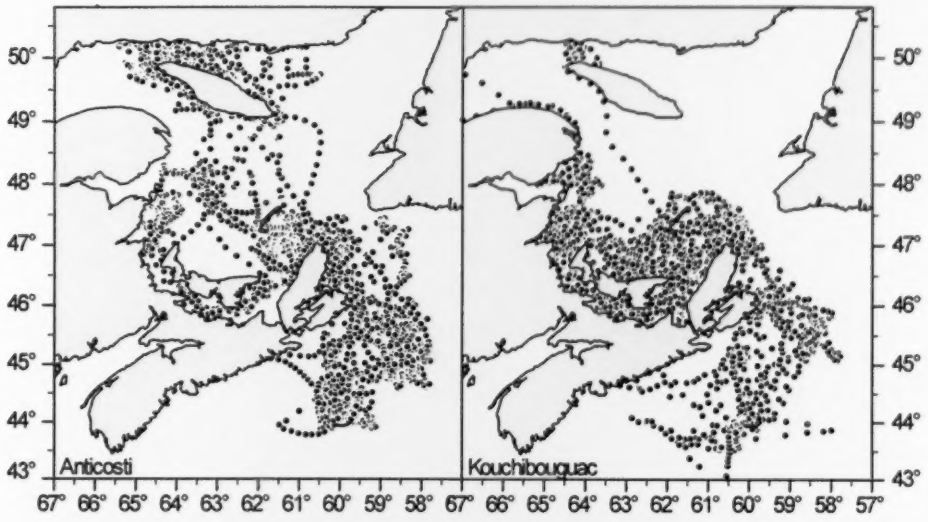

Figure 9. State-space model estimates of the locations of the ten seals tagged at Anticosti Island (left) and ten randomly selected seals from those tagged at Kouchibouguac (right).